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Injection locked oscillator lock detector

N.B. Buchanan, V.F. Fusco

This letter presents a simple circuit that is able to indicate if an injection locked oscillator is in the locked condition by providing a “high” or “low” output. The detector is compatible with most injection locked oscillators as all that is required is access to the low frequency bias circuit, with no direct access needed to the RF/microwave signals. To prove the universal nature of the lock detector it is successfully demonstrated practically for two scenarios, (i) a 1 GHz injection locked VCO, (ii) a 60GHz SiGe VCO MMIC.

Introduction: Injection locking in oscillators is a well known phenomena [1]. Injection locked oscillators, due their simple architecture, have been used in applications such as medical sensors [2] and frequency dividers for mm-wave PLL’s [3]. Low power transmitters for wireless sensor networks [4] have been shown to have improved efficiency by using an injection locked oscillator on their output stage. Injection locked oscillators have been shown in [5] to be capable of low loss clock distribution around a large circuit. In [6] the injection locked oscillator was used in a variety of configurations in order to simplify mm-wave phase locked loop architectures. Despite the potential advantages of injection locked oscillators, the aforementioned applications all have one thing in common, that is, they are rendered completely inoperable if the oscillators are not operating in their injection locked region. In addition, in some applications, e.g. transmitters, may produce unwanted out of band emissions if injection locking is not maintained.

Changes in the external environment such as temperature variation can cause unwanted variation in the oscillator’s free running frequency. External circuit conditions such as frequency pulling by load variation or frequency pushing caused by power supply voltage variation can also lead to erratic behaviour. For example [2] gave a detailed study on injection locked oscillator temperature variation in order to ensure that the medical sensor presented was reliable enough for normal everyday use. The scenario of oscillators drifting out of lock can quite easily occur since oscillators used for injection locking often exploit low Q circuits to maximise the locking range.

What is essential in these injection locking scenarios is a simple method to confirm that the oscillator is in the injection locked condition, i.e. an injection locked oscillator lock detection circuit. There are already existing methods that can determine if an oscillator is injection locked, e.g. by examining its frequency spectrum. Here a non-symmetrical sideband distribution [7] indicates that the oscillator is out of lock. This method is suitable for laboratory testing, but far too complicated to be implemented on a device such as a sensor. Lock detection can also be carried out by feeding the oscillator signal and injection locking signal to a mixer circuit to determine if zero beat frequency is present. In [8] a 60 GHz subharmonically locked oscillator was presented, with a lock detector based on a mixer circuit. This approach requires the additional mixer component to operate at mm-wave and also requires that both the injection locked oscillator signal and injection locking signals are available to be presented to the mixer. In some cases separate access to these two signals may require the use of a directional coupler, or circulator. These approaches add complexity and are counterproductive to the simplicity obtained by the use of the injection locked oscillator. The purpose of this letter is to present a much simpler injection locked oscillator lock detect circuit which can be implemented using only a few low frequency components, regardless of the RF frequency of oscillation. This letter will present an injection locked oscillator lock detect circuit which will be experimentally validated for two scenarios, (i) a 1 GHz injection locked oscillator, (ii) a 60GHz SiGe VCO MMIC.

Lock detector operation: The block diagram of the lock detector circuit which operates on the principle of self oscillating mixing is shown in Fig. 1(a). When the oscillator frequency, F_{OSC} , is not injection locked to the injection locking signal F_{INJ} , i.e. when $F_{INJ} \neq F_{OSC}$ the beat frequency $F_{INJ} - F_{OSC}$ appears across the DC biasing resistor R. When the oscillator is injection locked, $F_{INJ} = F_{OSC}$ then no beat frequency is present. Thus the presence/absence of an AC beat frequency on the bias supply can be

reliably used to determine if the oscillator is injection locked by means of simple, low frequency, circuits.

Referring to the lock detector circuit of (Fig. 1(a)) the voltage across the series resistor, R, indicates the presence of a beat note when the oscillator is out of lock. When the AC beat note signal is present it will pass through C to the amplifier and is rectified by a diode detector, smoothed by a low pass filter and fed to the inverting input of a comparator to give lock indication. In this case the detector output $V_{DET} > V_{COMP}$ and the comparator output goes low to indicate that the locked condition is lost. When the oscillator is injection locked then no AC beat note is present and $V_{DET} < V_{COMP}$ producing a high output from the comparator indicating that the locked condition has been obtained.

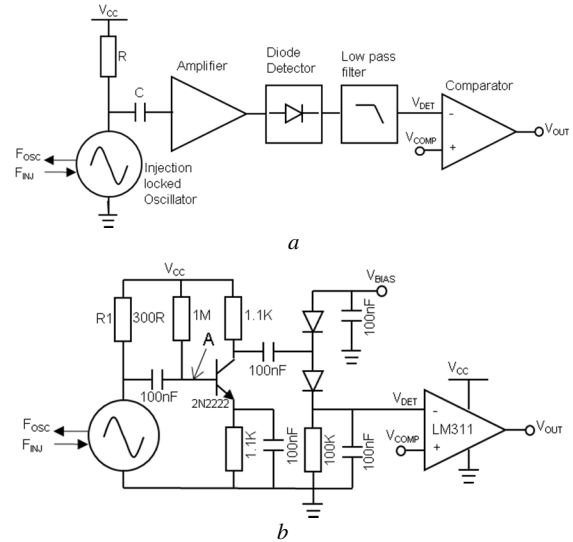


Fig. 1 Injection Locked Oscillator Lock Detect Circuit

a Block diagram

b Detailed schematic

Measured results for 1 GHz VCO: A 1 GHz mini circuits POS1025 VCO was used as the injection locked oscillator, which was confirmed by measurement, to have a reasonable injection locking bandwidth (8 MHz @ 0 dBm input power). To confirm that the VCO was unlocked, a 0dBm injection locking signal was applied to the VCO output, and the output frequency spectrum measured with a spectrum analyser. The injection locking frequency was varied until the signature non-symmetrical sideband distribution of Fig. 2(a) was obtained, confirming that the oscillator was not in the injection locked region. Now the spectrum analyser was connected across the DC supply series resistor (with a DC block present) to reveal that the beat frequency was recoverable with an amplitude of -39 dBm Fig. 2(b). This level indicates a self oscillating mixer conversion loss of 39 dB, which is likely explained by the internal DC decoupling capacitor of the VCO, which shunts the AC beat frequency signal to ground. This was confirmed by measurements with an LCR bridge showing the POS1025 to have a 1nF decoupling capacitor from the DC bias to ground. The lower conversion gain is overcome by the single stage common emitter amplifier, Fig. 1(b).

The VCO was now measured with the injection locked oscillator lock detect circuit as per Fig. 1(b). The amplitude of the AC beat frequency was measured at point (A), Fig. 1(b) using an oscilloscope. The results of Fig 3 show (dotted line) that the AC beat frequency amplitude is produced in the region of 2 – 16 mV p-p, becoming larger as the injection locking frequency is approached. When the oscillator is injection locked, the beat frequency amplitude falls to zero. At this point the value of V_{COMP} (Fig. 1(b)) was set to the point where the comparator was just producing an output of +VCC. It was then confirmed that moving the injection locking frequency to the unlocked region then switched the comparator output to 0V. To ensure the rectifier diodes were operating in the correct region the value of V_{BIAS} was set to 0.75V. The results of Fig 3 (solid line) show, for 0dBm injection locking power, that the locked condition is detected by the comparator over the locking range of 8 MHz.

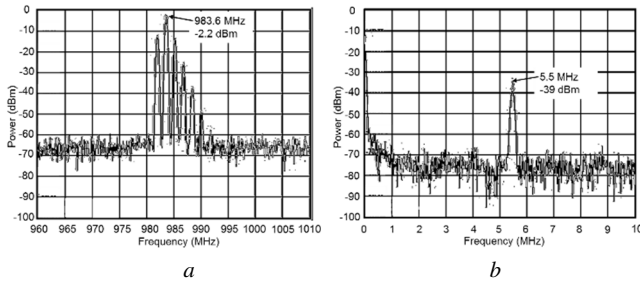


Fig. 2 1 GHz Injection locked oscillator frequency spectrums
a Unlocked output spectrum
b Beat frequency component produced on DC bias

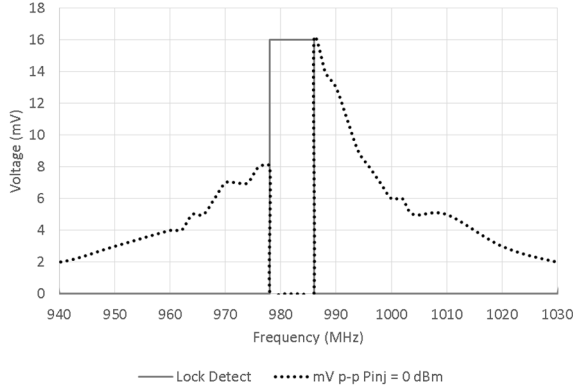


Fig. 3 Lock detector results for 1 GHz injection locked oscillator

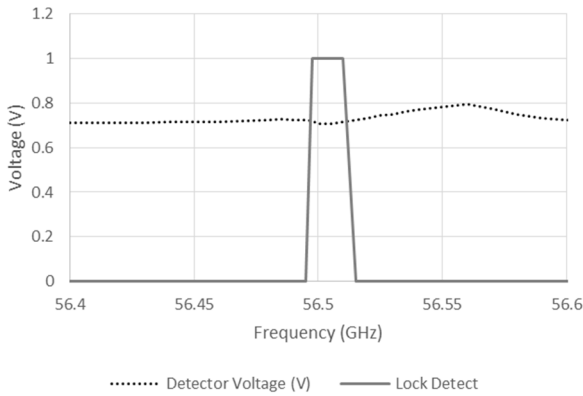


Fig. 4 Lock detector results for 60 GHz SiGe MMIC VCO

Measured results for 60 GHz SiGe MMIC oscillator: Next a 60GHz MMIC VCO was measured with the lock detect circuit. The MMIC was reported in more detail in [9] and was fabricated, using the Infineon 0.35 μm SiGe HBT process. The MMIC was measured via on wafer probing, using a Cascade Summit 12000 series semiautomatic probe station, connected to an Agilent 110 GHz mm-wave Vector network analyser. For this experiment, the vector network analyser internal signal generator was used as the injection locking source with an injection locking power of -10 dBm. The measured results of Fig. 4 (dotted line) show the value of the DC rectified voltage (V_{DET} in Fig. 1(b)), versus the injection locking frequency. In comparison to the 1 GHz VCO it was more suitable in this case to use the DC rectified voltage V_{DET} , due to additional high frequency “noise” superimposed on the AC beat frequency, making the isolation and measurement of the beat frequency p-p amplitude more challenging. Fig. 4 shows that a reduction in the DC rectified voltage (indicating the absence of the beat frequency) is observed between 56.495 – 56.515 GHz. This is successfully detected by the comparator, Fig. 4 (solid line), showing an injection locking bandwidth of 20 MHz.

Conclusion: This letter has successfully addressed a significant challenge with injection locked oscillators, namely, that there is no simple method to detect if the oscillator is in the injection locked region. Other reported methods of sensing if an oscillator is injection locked are complicated,

requiring additional microwave/mm-wave components. This letter has shown a simple and reliable method of detecting if the oscillator is in the injection locked region by using only a small number of low frequency components. The approach can be universally applied to almost any type of injection locked oscillator as all that is required is the ability to recover a low frequency beat signal from the power supply. To prove the universal nature of the lock detector, this letter has successfully proven its operation experimentally for two very different scenarios of (i) a 1 GHz VCO module and (ii) a 60 GHz SiGe MMIC VCO.

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